EFFECT OF MILLING TIME ON MECHANICAL AND PHYSICAL BEHAVIOR OF ALMMC REINFORCED WITH AL_2O_3

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurently submitted for award of other degree.

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ABSTRACT

This thesis is to investigate the effect of milling time to the mechanical and physical properties Aluminum metal matrix composite reinforced with alumina. The objective of this thesis is to study the effect of milling time on mechanical and physical properties of powder materials. This thesis also to characterize the hardness and microstructure of Aluminum MMC produced by reinforced aluminum with alumina using powder metallurgy process. The thesis describes the powder metallurgy process to produce Al MMC reinforce with Al_2O_3. The powder metallurgy process consist of three main process which is milling process, compaction process and sintering. The milling process has big influence on the characteristic of powder materials, due to particle deformation followed by welding and fracturing particles. Mechanical milling is a process involving repeated deformation, welding and fracture. The mechanically milled show finer and better distribution of reinforcement particle what lead to better mechanical properties of obtained product. The results are increasing the milling time significant to improve the mechanical and physical properties of the Aluminum metal matrix composite produced.

ABSTRAK

Tesis ini adalah untuk menyelidik kesan masa kisaran terhadap ciri-ciri mekanikal dan fizikal aluminium besi campuran. Tujuan tesis ini adalah untuk memahami kesan masa kisaran terhadap ciri-ciri mekanikal dan fizikal kepada bahan serbuk. Tesis ini juga bertujuan untuk mengelaskan kekerasan dan struktur bahan aluminium besi campuran yang diperkuat menggunakan alumina. Tesis ini menyentuh tentang penghasilan aluminium besi campuran yang diperkuat dengan menggunakan alumina melalui kaedah serbuk metalurgi. Serbuk metalurgi terdiri daripada tiga proses utama iaitu proses kisaran, proses tekanan dan proses pensinteran. Proses pensinteran memberikan kesan besar terhadap cirri-ciri besi campuran melalui perubahan bentuk bahan campuran diikuti oleh penyambungan dan pemecahan biji-biji serbuk. Process kisaran menunjukkan kehalusan dan menyerataan serbuk penguat akan menghasilkan cirri-ciri fizik yang lebih baik bagi sesuatu bahan. Hasil yang diperolehi adalah dengan peningkatan masa kisaran, maka ciri-ciri mekanikal dan fizikal aluminium besi campuran akan bertambah baik.

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HV	Hardness Number
wt%	Weight Percentage

LIST OF ABBREVIATIONS

Al	Aluminum
Al_2O_3	Alumina
CFRP	Finate Element Method
CMC	Ceramic Metal Composite
FRP	Fiber Reinforced Particle
FEM	Finate Element Method
GRP	Glass Reinforced Particle
MMC	Metal Matrix Composite
PMC	Polymer Metal Composite
PRM	Particle Reinforced Material

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This project basically concentrates on how to produce the Aluminum metal matrix composite using the powder metallurgy process. The term “composite” broadly refers to a material system which composed of a reinforcement distributed in a matrix phase. Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase, e.g., polymer matrix, metal-matrix and ceramic composite. In Al MMCs one of the constituent is aluminum, which forms percolating network and is term as matrix phase. The other constituent is embedded in this aluminum matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Powder metallurgy contains three major steps which are mixing the matrix powders and reinforcement powders. It is carried out to obtain a desired powder distribution. After that, mixed powder will be compacted at certain pressure to produced green compaction material. After compaction, material produced will be sintered to transform compacted bond to much stronger metallic bonding. At the mixing process, time taken to mix the aluminum powder and alumina powder will be varied to get different properties of Al MMC produced. Then Al MMC will be test through several experiments to investigate its mechanical and physical properties.

1.2 PROBLEM STATEMENT

The demand for the light weight components have increased and to reduce the cost of the fabrication. These have led to increase use of the aluminum with the low cost of the fabrication that is the aluminum fabricated using powder metallurgy process. Aluminum powder metallurgy offers components with low density, excellent machinability and good response to a variety of finishing process. In addition, aluminum powder metallurgy parts can be further processed to eliminate porosity and improve bonding properties that compare to those conventional wrought aluminum products.

1.3 THE OBJECTIVES OF THE RESEARCH

The objective of the thesis is:

i) To study the effect of milling time on mechanical and physical properties of powder materials.

ii) To characterize the hardness and microstructure of Aluminum Metal Matrix Composite produced by reinforced Aluminum (Al) with Alumina (Al_2O_3) using powder metallurgy process.

1.4 OVERVIEW OF THE THESIS

Powder Metallurgy is a method of manufacturing reliable net shaped components by blending element powders together, compacting this blend into a die and sintere the pressed part in a controlled atmosphere furnace to bond the particle metallurgucally. The powder metallurgy process fabrication method is highly cost effective in producing parts at, or closed to final dimensions. Powder metallurgy provides advantages such as production of complex shapes to very closed dimensional tolerance and physical and mechanical properties of components can be controlled through the process parameters.

Mechanical milling or mixing, as a method of introducing the reinforcement particles, assures better distribution of the particles in the consolidated material (Lee et al, 1995). This process consists of repeated welding–fracturing–welding of a mixture of powder particles in a high-energy ball mill (Suryanarayana, 2001). The central event is that the powder particles are trapped between the colliding balls during milling and undergo deformation and/or fracture processes, depending upon the mechanical behavior of the powder components. Proper mixing is essential to ensure the uniformity of mechanical properties throughout the part. Even when a single metal is used, the powders may carry significantly in size and shape, hence they must be blended to obtain uniformity from part to part. The ideal mix is one in which all particle of each material are distributed uniformly. The correct determination of the milling time will ensure that the characteristics of the powder will be such as to enhance the final properties of the composite material (Fogagnolo et. al., 2002).

The powder metallurgy components can be produced by cold die compaction of the powder. Normally, die compaction of metal powder undergoes a number of stages, namely, initial compaction, which involves particle rearrangements. The physical properties such as particle size and shape greatly influence this initial stage. This is followed by the deformation, and here the mechanical properties and the quality of the particles are important factors, which control the compressibility behavior of the powder. The final stage of compaction is almost totally an upsetting of the bulk material. As a result, the powder compacted component is produced with inhomogeneous distributions of density and porosity.

Sintering is the process powder compacts are heated so that adjacent particles is bonded together by forming necking, thus resulting in a solid particle with improved mechanical strength compared to the powder compacted. This typically has two heating zones, the first removes the lubricant, and the second higher temperature zone allows diffusion and bonding between powder particles. The density of the component will change during sintering process, depending on the materials and the sintering temperature. These dimensional changes can be controlled by an understanding of the sintering parameters such as temperature and sintering time.

Aluminum possesses a combination of properties that make it extremely useful engineering material. Aluminum has a low density, making it particularly useful for transportation manufactured products. Aluminum also has good corrosion resistance in most natural environment due to tenacious oxide film that forms on its surface, effectively preventing further oxidation. Although pure aluminum has low strength, it can be reinforced to strength of about 690Mpa (W. F. Smith, 2004). Aluminum is nontoxic and is used extensively for food containers and packaging. The good electrical properties of aluminum make it suitable for many applications in the electrical industry. The relatively low prices of aluminum along with its many useful properties make this metal very important industrially.

Aluminum oxide is an amphoteric oxide of aluminum with the chemical formula Al_2O_3. It is also commonly referred to as ceramic materials that can be produced by the Bayer process from bauxite. Alumina most significant use is in the production of aluminum metal because of very hard and high melting point it is used as an abrasive on the alloys.

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure. There are several groups of the composites according to matrix, for example Polymer Matrix Composites, PMC (epoxy/C-fiber, epoxy/SiC-particle), Metal Matrix Composites, MMC (TiAl6V4/SiC-fiber, Al/Al2O3-particle), Ceramic Matrix Composites, CMC (C/SiC-particle, C/C-fiber) and others such as wood and concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to powder metallurgy process. The main process included milling the raw material (powder) which is Aluminum powder and Alumina powder (Al_2O_3), compacting milled powder and sintering process. A review of other relevant research studies is also provided. However, little information can be found on integrated durability evaluation methods. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort.

2.2 POWDER METALLURGY

Powder metallurgy is a method of manufacturing reliable net shaped components by blending element powders together, compact this blend in a die and sintering the pressed part in a controlled atmosphere furnace to bond the particle metallurgucally. The powder metallurgy process fabrication method is highly cost effective in producing parts at, or closed to final dimensions. Powder metallurgy provides advantages such as production of complex shapes to very closed dimensional tolerance and physical and mechanical properties of components can be controlled through the process parameters.

The industry is comprised of companies that make conventional powder metallurgy parts and products from iron and copper-base-powders; and companies that make specialty powder metallurgy products such as superalloys, porous products, friction materials, strip for electronic applications, high strength permanent magnets, magnetic powder cores and ferrites, tungsten carbide cutting tools and wear parts, metal injection molded parts and tool steels. There are international powder metallurgy industries in all of the major industrialized countries.

It has become one of the most common, most efficient processing techniques. Powder metallurgy components are being used in ever increasing quantities in a wide variety of industries as the technology combines unique technical features with cost effectiveness. Powder metal components are used in the aerospace industry for gears and engine parts. However, they are also found in automobiles, sporting goods, and everyday household items. It is important, then, to understand the process, as it is becoming even more common as time goes by.

Powder Metallurgy is a highly developed method of manufacturing reliable ferrous and nonferrous parts. Such metals used are brass, bronze, stainless steel, and iron. There are three basic steps in making a part: mixing elemental or alloy powders, compact the mixture in a die, and sintering the part in a controlled atmosphere furnace to bond the particles metallurgically. This process can be seen in Figure 1.1.

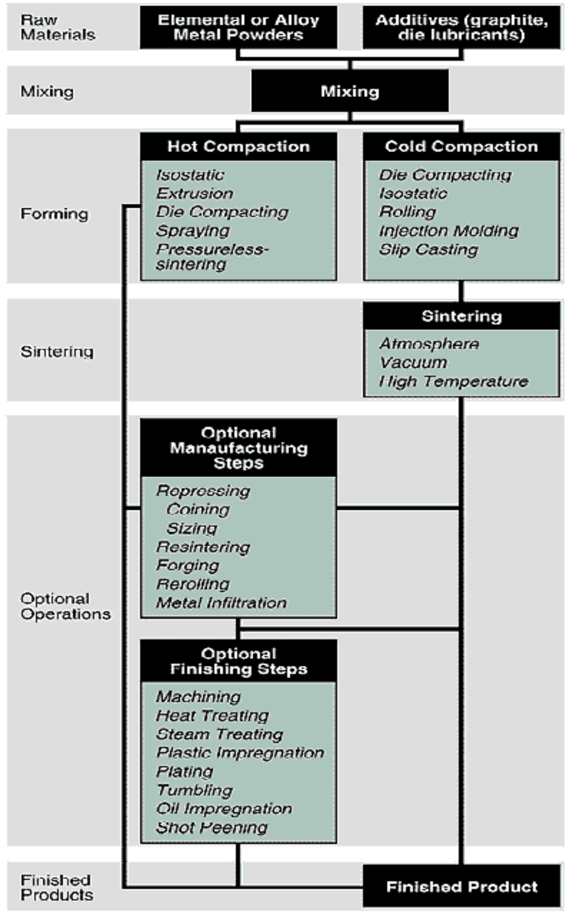

Figure 2.1: Powder Metallurgy Process

Source: Verlinden et al. (1994)

As with any manufacturing process, there are advantages and disadvantages that must be taken into consideration when designing parts. Some of the benefits and limitations of powder metallurgy are discussed in this section. The advantage of powder metallurgy is the powder metallurgy process typically uses more than 97% of the starting raw material in the finished part. This means that powder metallurgy conserves energy and materials. By conserving materials it is cost effective. And because parts can be produced at, or very close to, final dimensions, machining is very limited. Productions rates can be very high as well. Beside that another advantages is minimizes machining, minimizes scrap losses, maintain close dimensional tolerances, produces good surface finishes, provides materials which may be heat-treated for increased strength or increased wear resistance, provides controlled porosity for self-lubrication or filtration, facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metalworking processes and suited to moderate to high volume components production requirements.

There are limitations to the powder metallurgy process. Some of these disadvantages can be costs of powder production, limitations on the shapes and features which can be generated, e.g. process cannot produce reentrant angles by fixed die pressing or radial holes in vertically pressed cylinders and the size will always change on sintering. However, there are some design choices that can be made to make the powder metallurgy process more suitable for a part. For example, sharp corners should be avoided. Instead small radiuses to make the powder metallurgy process more applicable should replace corners. Also, the size change during sintering can be predicted, as it depends on a number of controlled factors including as-pressed density.

Because of its versatility, the powder metallurgy process is being used to produce many thousands of different parts in most product and equipment-manufacturing industries. The applications of powder metallurgy parts in these industries fall into two main groups. The first includes applications in which the part is impossible to make by any other method. Powder metallurgy is the only way of forming vital metals such as tungsten carbide, dispersion-strengthened materials, superalloys and self-lubricating bearings. Porous bearings and many types of magnetic cores are exclusively powder metallurgy products. The second group of uses consists of mechanical and structural parts that compete with other types of metal forms, such as machined parts, castings, and forgings. Examples of such powder metallurgy products include lock hardware, garden tractors, snowmobiles, automobile engines and transmissions, auto brake and steering systems, washing machines, power tools and hardware, sporting arms, copiers and postage meters, off-road equipment, hunting knives, hydraulic assemblies, x-ray shielding, oil and gas drilling wellhead components, fishing rods, surgical instruments, gears, cam shafts, and wrist watches.

2.2.1 MILLING PROCESS

Powders made by different processes have different sizes and shapes and must be well mixed-impart special physical & mechanical properties & characteristic to the powder metallurgy product. Proper mixing is essential to ensure the uniformity of mechanical properties throughout the part. Even when a single metal is used, the powders may carry significantly in size and shape, hence they must be blended to obtain uniformity from part to part. The ideal mix is one in which all particle of each material are distributed uniformly.

Lubricants can be mixed with the powders to improve their flow characteristic. They reduce friction between the metal particles, improve flow of the powder metals into the dies and improve die life. Lubricants typically are stearic acid zinc strearate in a proportion of from 0.25 to 5% by weight. Other additives such as binder also used to develop sufficient green strength and also can be used to facilitate sintering.

Irregularly shaped particles are required to ensure that the as-pressed component has a high green strength from the interlocking and plastic deformation of individual particles with their neighbors.

One disadvantage of this technique is the differences in pressed density that can occur in different parts of the component due to particle/particle and die wall/particle frictional effects. Typical as-pressed densities for soft iron components would be 7.0 g/cc, i.e. about 90% of theoretical density. Compaction pressure rises significantly if higher as-pressed densities are required, and this practice becomes uneconomic due to higher costs for the larger presses and stronger tools to withstand the higher pressures.

The purpose of mixing is to provide a homogeneous mixture and to incorporate the lubricant. Some lubricants that are commonly used are stearic acid, stearin, metallic stearates, especially zinc stearate, and increasingly, other organic compounds of a waxy nature. The main function of the lubricant is to reduce the friction between the powder and the surfaces of the tools (e.g. die walls, core rods) along which the powder must slide during compaction. This helps with getting desired uniformity of density from the top to the bottom of the compact. It also makes it easier to eject the compact, which minimizes the tendency to form cracks.

The lubricant must be selected carefully, as it may affect both green (unsintered) and sintered strengths. This is especially true if any residue is left after the organic part has decomposed.

Over-mixing can occur and should be avoided. This increases the apparent density of the mix. Over-mixing also further reduces the green strength of the subsequent compacts probably by completely coating the whole surface of the particles, thereby reducing the area of metal-to-metal contact on which the green strength depends.

Table 1.1: Common Milling Time According to Authors

No.	Author	Raw Material Used	Milling Time
1	Adamiak et al.	Aluminum + Titanium Aluminite	2, 10, 18
2	Fogagnolo et al. (2002)	Aluminum (PM6061) + Si_3N_4	0, 2, 4, 6, 8, 10
3	Fogagnolo et al. (2003)	Aluminum + AlN	0, 1.5, 3, 4.5, 6, 8, 10
4	Hesabi et al. (2006)	Aluminum + Al_2O_3	0, 2, 8, 12, 16, 18, 20
5	Simchi et al. (2007)	Aluminum + SiC	2, 8, 12, 16
6	Zhang et al. (2004)	Cu-Al_2O_3/ Al-Al_2O_3	1, 8, 40, 80

Table 1.1 shows the common milling time that the authors used in their research. Milling time will varied with some interval or incrementation. For each increment of time to mill the powders, the product will be test to see the effect such as physical and mechanical behavior.

2.2.2 COMPACTION PROCESS

Generally, the powder metallurgy components can be produced by cold die compaction of the powder. Normally, die compaction of metal powder undergoes a number of stages, namely, initial compaction, which involves particle rearrangements. The physical properties such as, particle size and shape greatly influence this initial compaction stage. This is followed by the elasticplastic deformation, and here the mechanical properties and the quality of the particles are important factors, which control the compressibility behavior of the powder. The final stage of compaction is almost totally an upsetting of the bulk material. Hence, the work hardening of the particle affects the hardness of the final product.

As a result, the powder compacted component is produced with inhomogeneous distributions of density and porosity. This is due to the frictional forces in between particles (internal friction), and/or between the powder and the container walls (powder/container friction). This, evidently, causes shrinking during distortion of the product. However, some powder metallurgy components are required to have a certain percentage of porosities so that pores may be filled with gases, liquids and self-lubricants for specific applications. Needless to say, the green density of compact has direct influence on the densification and porosity of the product and hence the strength. It seems that all the previously developed expressions depend totally or partially on experimental factors, due to the unknown parameters.

Studies were performed involving the simulation of powder compaction using the FEM and based on the elastic-plastic behavior of large displacement, where the powder is considered as a continuum which exhibits plastic deformation under applied external pressure. (Justino et al., 2004). The cold die compaction of powder metallurgy involves several complex parameters, such as, rearrangements, fragmentation, work hardening and others making it complicated to analyze theoretically the mechanism of compaction. Previously published works in general, rely on empirical or semi-theoretical expressions to relate the green density as a function of process parameters. Recently, the authors have published an analysis of the cold die compaction of powder materials based on the axi-symmetric solution of large deformation, but it did not elaborate on other important parameters (Al-Qureshi et al., 2005).

2.2.3 SINTERING PROCESS

Sintering is the process powder compacts are heated so that adjacent particles is bonded together by forming necking, thus resulting in a solid article with improved mechanical strength compared to the powder compact. This process will results in an increase in the density of the part. There are some processes such as hot isostatic pressing which combine the compaction and sintering processes into a single step.

After compaction the components pass through a sintering furnace. This typically has two heating zones, the first removes the lubricant, and the second higher temperature zone allows diffusion and bonding between powder particles. A range of atmospheres, including vacuum, are used to sinter different materials depending on their chemical compositions. As an example, precise atmosphere control allows iron/carbon materials to be produced with specific carbon compositions and mechanical properties.

The density of the component can also change during sintering, depending on the materials and the sintering temperature. These dimensional changes can be controlled by an understanding and control of the pressing and sintering parameters, and components can be produced with dimensions that need little or no rectification to meet the dimensional tolerances. Note that in many cases all of the powder used is present in the finished product, scrap losses will only occur when secondary machining operations are necessary.

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.